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Texture of Cooked Potatoes (*Solanum tuberosum*). 3. Preheating and the Consequences for the Texture and Cell Wall Chemistry

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Two potato cultivars representing extremes with regard to the texture of the cooked product were divided into subcategories based on size and dry matter (DM) content. The effects of the preheating temperature and time on both the instrumentally determined firmness and the sensory-perceived firmness were measured and compared. Increasing the preheating time at 60 °C followed by cooking resulted in greater force required to fracture the tissue, an increase in perceived firmness, and a less mashable product. A principal component analysis showed that with higher DM contents of the potato samples, preheating resulted in a larger force required to fracture the tissue and a firmer product. The changes in fracture force were not linearly related with the changes in perceived firmness. The effects of preheating on the pectin methylesterase (PME) activity, the enzyme assumed to be responsible for the firming effect upon preheating, showed that the activity of this enzyme remained rather constant during preheating at 60 °C for 1 h. Preheating at 78 °C for 10 min abolished virtually all PME activity. To obtain insight into the consequences of preheating and preheating followed by steam cooking on the yield and composition of the cell wall material (CWM) of potatoes, a cell wall isolation followed by a pectin fractionation study was performed. Attention was also paid to the consequences of the processing conditions applied on the chemical composition of the CWM and the sequentially extracted pectic fractions. Preheating resulted in an increase in yield of the CWM of cooked potatoes and, as a consequence, all of the sequentially extracted fractions, including the residue. Preheating did not have a pronounced effect on the composition of the pectin of the sequentially extracted fractions. This altogether strongly indicates that preheating causes a PME-based firming effect, resulting in an decrease in pectin degradation and, as a consequence, a larger yield of CWM. It seems reasonable to assume that this increase in amount of CWM results in a firmer texture. The contribution of starch-based degradation products to the texture after preheating can, however, not be excluded.

KEYWORDS: Potato; preheating; pectin; cell wall; composition; yield; texture

INTRODUCTION

The pectin moiety of the cell wall is, for fresh fruits and vegetables, subject to continuous modifications. Changes in the chemical composition of the cell wall pectin are, for example, observed during the growth of green beans (*1*), ripening of tomatoes (*2*), and storage of potatoes (*3*). Despite the observed compositional changes in the cell wall pectin during storage, the sensory-perceived texture of steam-cooked potatoes did not change during this period (*3*, *4*). For potatoes it was concluded that the contribution of the pectin moiety of the cell walls to the texture is predominated by other factors such as dry matter (DM) and starch (**3**).

In the potato-processing industry blanching is a unit operation preceding the final cooking (production of flakes or granules) or frying (production of French fries) process. This preheating process is used to gelatinize the starch and to inactivate enzymes. It has been described that the blanching time and temperature can have an effect on the firmness of both the cooked and sterilized product (*5*, *6*). Indirect but strong evidence points to the role of the enzyme pectin methylesterase (PME). PME demethylates pectin. This demethylated pectin is less susceptible to heat-induced β-degradation. The direct consequence of the activity of PME, a decrease in the degree of pectin methylation, is in general not very obvious (*7*, *8*). The indirect consequence, an increase in firmness, is more pronounced (*5*, *6*).

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Recently Van Dijk and Tijskens (*6*) have reported on the mathematical relationship of the increase in firmness of the cooked product as a consequence of preheating. They related the total exerted effect of PME during preheating with the decrease in pectin degradation during cooking and the consequences for the final firmness of the product. Their approach was based on the assumption that, after turgor loss due to heat-induced membrane damage, the firmness of plant tissue is based on fixed and variable firmness parts. The relative inert cellulose−hemicellulose matrix represents the fixed firmness part. The variable firmness part is represented by the pectin moiety of the cell wall. Heat or enzymes can degrade the latter part. Superimposed on the cell wall related firmness are the contributions of cellular products such as starch. In addition, the overall structure and shape of individual cells and the organization of the cells within the plant tissue all add to plant-specific texture characteristics.

Firmness and changes in firmness can be quantified using either the subjective approach of sensory analysis (*3*, *4*), or the objective approach of rheological measurements (*9*−*11*). For potatoes no obvious relationship exists between the results of these two approaches (*10*). Recently it was also observed that changes in pectin composition are not associated with changes in the sensory-perceived texture of steam-cooked potatoes (*12*). Blanching of potatoes is a common practice in the potato-processing industry. Therefore, it seems worthwhile to study the consequences of preheating on the sensory-perceived and instrumentally measured firmness of the steam-cooked product. Because the tissue firming is ascribed to PME, the activity of this enzyme during blanching and changes in yield and composition of the pectin moiety in the cell wall are subjects of this study as well. Because the DM content, which is manly caused by starch, strongly relates with the texture of potatoes, two potato cultivars were studied representing extremes with regard to texture.

MATERIALS AND METHODS

Plant Material and Storage Conditions. Potato tubers from cv. Nicola and Irene were grown under standard agricultural conditions in 1996 in clay soil in The Netherlands. Lots of a restricted population of identical growth history were stored after harvest at 6 °C using sprout inhibitor (chloropham). One lot of potatoes was investigated immediately after harvesting (field-run experiment). The remainder was stored. Before analysis, the lots were divided into two size categories: 30−45 mm (small) and 55−65 mm (large).

Dry Matter Distribution. The DM distribution of the field-run potatoes was determined for batches (400 tubers) as described previously (*1*). From each distribution 25% of the potatoes ware sampled at the low end and 25% of the potatoes at the high end, representing the subcategories with low and high DM contents, respectively. The DM content of each subcategory based on underwater weight analysis (DM_{UWW}) was calculated as the average DM content of the potatoes within a subcategory.

For sorting the potatoes stored for 5 months the same DM_{UWW} limits were used compared with the field-run potatoes. Salt solutions corresponding to the density of these limits were used to select the potatoes of both the low and high DM contents. For both the field-run and the stored potatoes, the remainder of the batch, representing the medium DM fraction (50% of the total batch), was discarded.

Dry Matter and Starch Contents. The DM content, as determined by oven drying (DM_{DRY}), and starch content were determined as described previously (*1*).

Preheating of the Samples. From 60 peeled potatoes, belonging to the same sample, cubes of 10 × 10 × 10 mm were cut. The cubes were randomized, separated in groups of 60 cubes, and transferred to beakers containing 800 mL of demineralized water of either 60 or 78 °C. At 60 °C the cubes were preheated (in a water bath) during either 0, 5, 10, 15, 30, or 60 min. At 78 °C the preheating time was in all cases 10 min. The treatment at 78 °C during 10 min was used because this temperature−time combination is common practice in the potato flakes and granules processing industry. After the heat treatment, the cubes were separated from the water by sieving. Ten cubes were frozen in liquid nitrogen and stored at − 20 °C for analysis of the PME activity. The remaining cubes (50) were steam-cooked for 10 min. Twenty cubes were used for sensory analysis, and 10 cubes were used for instrument-based firmness measurements.

Table 1. Dry Matter Content (Milligrams per Gram of Fresh Weight) Based upon Underwater Weight Measurements (DM_{UWW}) and Drying (DM_{DRY}) and Starch Content (Milligrams per Gram of Fresh Weight) of Potato Samples Categorized by Size and Dry Matter Content

			field run			long storage	
cultivar	size	DM level	DM_{UWW}	DM_{DRY}	starch	DM_{DRY}	starch
Nicola	small	low	147 ± 1.1	151	94	142	63
		high	196 ± 1.0	200	157	205	100
	large	low	171 ± 1.0	173	105	177	86
		high	205 ± 0.8	210	139	201	109
Irene	small	low	205 ± 1.4	225	140	214	126
		high	257 ± 0.7	276	182	267	169
	large	low	221 ± 0.9	234	152	233	151
		high	252 ± 0.6	275	189	256	173

Texture Measurements. *Sensory Texture Analysis.* Sensory texture analysis was performed in duplicate using a fully randomized set of potato samples, prepared as described above, offered to two potato expert panelists. Eight texture-related mouthfeel (M) descriptors (firm-M, crumbly-M, moist-M, sticky-M, grainy-M, waxy-M, mealy-M, and mashable-M) were used to describe the samples (*3*, *4*). Sensory analysis was performed only on the potatoes stored for 5 months. Training and maintenance of the panel was as described previously (*3*, *4*).

Firmness Measurements. Potato firmness was assessed by measuring the force required to break the tissue, using the wedge method as described by Vincent et al. (*9*). Firmness measurements were performed using a Universal Testing Machine, Instron 4202, using a wedge with an angle of 10° at a rate of 4 mm·min^{-1}. The maximum force measured to break the tissue was used for further analysis of the data.

Chemical Measurements. *Pectin Methylesterase Activities.* Forty milligrams of sample was extracted with 1 M NaCl. This reaction mixture was purified on a prepacked Sephadex G-25 M column (Pharmacia PM 10), as described previously (*1*). The reaction mixture for the enzyme activity determination consisted of 100 μL of sample solution, 100 μL of 3 M NaCl, 2000 μL of 0.2% pectin, 0.04% BTB (pH 7.8), and 800 μL of Milli-Q water. The E_{616} was monitored for 3 min and the reaction rate determined from the linear part of the resulting graph (*13*).

Cell Wall Analysis. A pectin fractionation study was performed on the small potatoes with high DM content of cv. Irene, stored for 5∼ months. Potato cubes (see above) were either not pretreated or preheated either for 30 min at 60 °C or for 10 min at 78 °C. Half of each sample was steam-cooked for 10 min. After preparation, the samples were frozen in liquid nitrogen followed by freeze-drying. The overall cell wall content, the fractionation of the cell wall material (CWM) into distinct pectic fractions, and the monosaccharide composition of each fraction were determined as described previously (*12*). Anhydrouronic acids were determined as described by Ahmed and Labavitch (*14*).

Data Analysis. Data analysis was performed as described previously (*3*).

RESULTS

Dry Matter and Starch Contents. In **Table 1** the DM contents, DM_{UWW} and DM_{DRY}, as well as the starch content of the field-run and stored potatoes are presented. The DM_{UWW} values for cv. Nicola are substantially lower than the values determined for the previous harvest (*3*). Although significant ($p \geq 0.95$), the differences are less pronounced for cv. Irene.

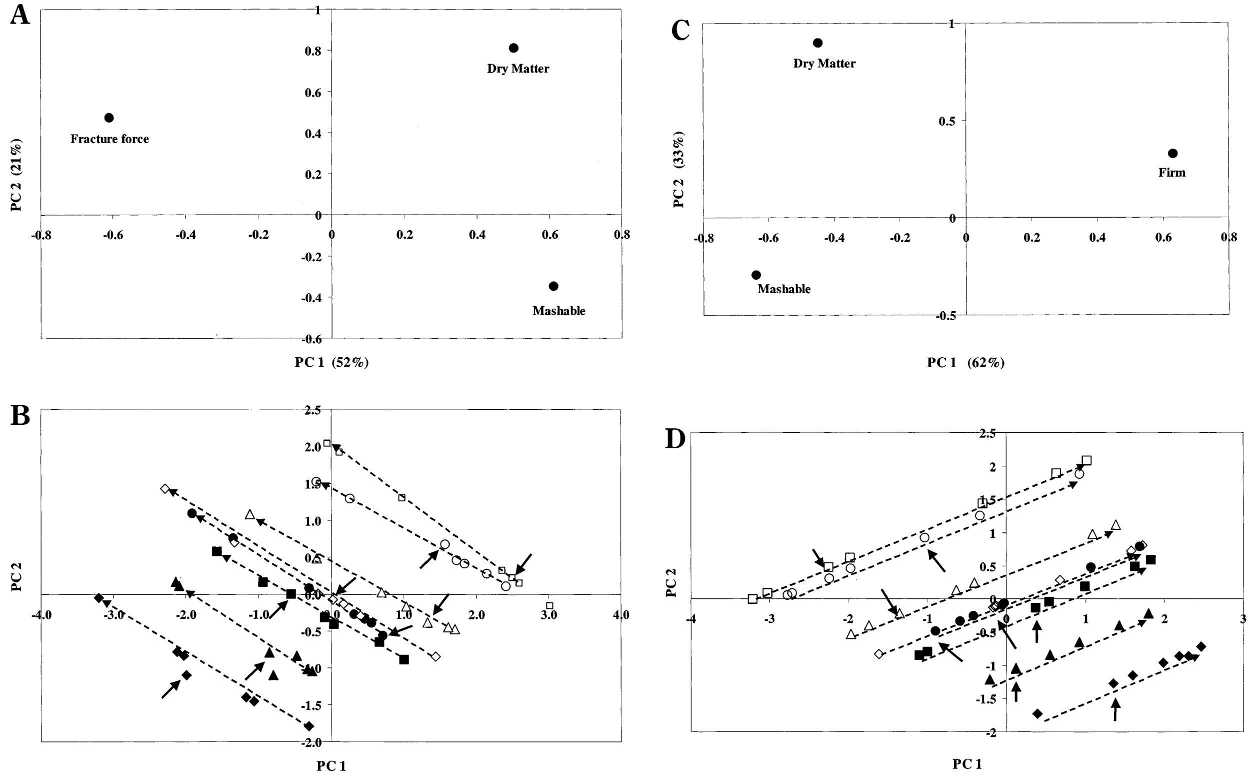


Figure 1. Principle component analysis of the effect of preheating on the tissue breaking force and sensory descriptors firm and mashable in relation to the DM of cooked potatoes; (A) loadings plot of the fraction force, the descriptor mashable, and the DM content on the first and second principle components; (B) sample scores of preheated, cooked potato samples on the first and second principle components of (A); (C) loadings plot of the descriptors firm and mashable and the DM content on the first and second principle components; (D) sample scores of preheated, cooked potato samples on the first and second principle components of (C); (◆) small potatoes with low DM content; (■) small potatoes with high DM content; (▲) large potatoes with low DM content; (●) large potatoes with high DM content. Dashed arrows relate the change in texture of the samples belonging to the same subcategory at increasing preheating time (arrow direction) at 60 °C; solid arrows represent samples preheated at 78 °C for 10 min. Open symbols illustrate cv. Irene and solid symbols, cv. Nicola.

The average coefficients of variation of these 16 samples for DM_{DRY} and for starch were, respectively, 0.74 and 2.8%. Previously, linear relationships were established among DM_{UWW}, DM_{DRY}, and the starch content (*3*). Using these relationships, prediction of DM_{UWW} on the basis of the values measured for DM_{DRY} resulted in a value for the root-mean-squares error of prediction (RMSEP) of 14.9 (mg/g of fresh weight), of 25.4 (mg/g of fresh weight) for the prediction of DM_{UWW} on the basis of the values measured for starch, and of 27.4 (mg/g of fresh weight) for the prediction of the amount of starch on basis of the values measured for DM_{DRY}.

Effects of Preheating on the Sensory-Perceived Texture and Instrumentally Measured Firmness of Cooked Potatoes. Previously, research was performed on the relationships between the DM content, storage, and sensory-perceived texture of steam-cooked potatoes (*3*). Here the consequences of preheating preceding steam-cooking on the sensory-perceived texture were studied. With regard to the sensory analysis, it is realized that the number of assessors is too low to obtain statistically significant information. However, the main aim was to observe general trends in the texture development of potatoes as a consequence of preheating rather than to obtain statistically significant analytical sensory information. The sensory data clearly show that with increasing preheating time potatoes become firmer and less mashable after cooking. The wedge fracture test confirms that at increasing preheating time potatoes become firmer (*11*).

The results of a principal component analysis (PCA) of the effect of preheating on the instrumentally measured fracture force and sensory descriptor mashable-M, taking the dry matter (DM_{UWW}) into account, is shown in **Figure 1A**,**B**. In **Figure 1C**,**D** the results of a PCA of preheating on the descriptors firm-M and mashable-M, also taking the dry matter (DM_{UWW}) into account, are shown. In **Figure 1A** the scores plot and in **Figure 1B** the loadings plot are shown for the combined PCA of the measured fracture force and sensory descriptor mashable-M. The first and second PCs explain 52 and 21% of the variance, respectively. In **Figure 1C** the scores plot and **Figure 1D** the loadings plot are shown for the sensory descriptors firm-M and mashable-M. The first and second PCs explain 62 and 33% of the variance, respectively.

In **Figure 1B**,**D** parallel vectors can be observed. Each vector describes the change in texture, as represented by the fracture force and descriptor mashable-M and by the descriptors firm-M and mashable-M, respectively, as related to the DM_{UWW} content of the potato sample analyzed. The length of each vector, running through the data points of one sample, describes the change in texture as a consequence of increased preheating time, running from 0 to 60 min of preheating at 60 °C. As can be clearly seen from the information presented in **Figure 1B**,**D**, the higher the DM content of a sample, the more pronounced the effect of preheating on the change in the values of the descriptors *firm-M* and mashable-M. Preheating at 78 °C for 10 min results in a texture similar to that obtained with preheating for 5−10 min at 60 °C.

A frequently addressed question is the relationship between the sensory-perceived texture and the instrumentally measured firmness (*10*, *16*, *17*). In **Figure 2** the relationship between the

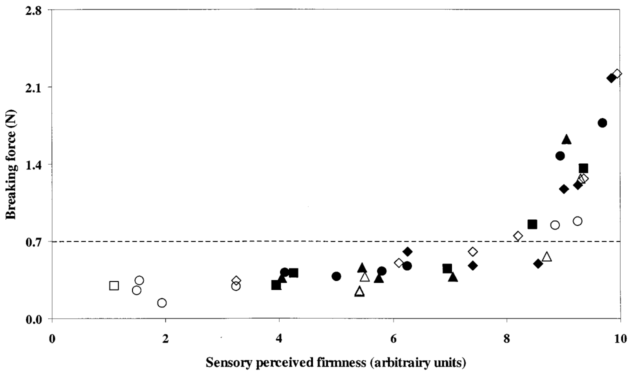


Figure 2. Relationship between sensory-perceived firmness and tissue breaking force of preheated, cooked potato samples: (◆) small potatoes with low DM content; (■) small potatoes with high DM content; (▲) large potatoes with low DM content; (●) large potatoes with high DM content. Open symbols illustrate cv. Irene and solid symbols, cv. Nicola.

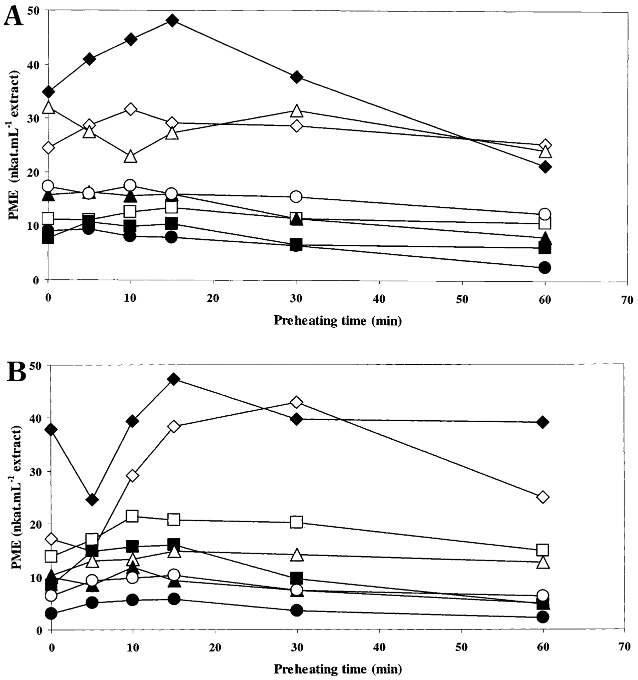


Figure 3. Effect of preheating time on the extracted pectin ethylesterase activity of cv. Irene (A) and cv. Nicola (B): (◆) small potatoes with low DM content; (■) small potatoes with high DM content; (▲) large potatoes with low DM content; (●) large potatoes with high DM content. Solid symbols reprsent potatoes directly after harvest and open symbols, potatoes after 5 months of storage.

sensory-perceived texture attribute firm-M and the force required to fracture the tissues is plotted. Within this plot two regions can be observed. Up to a breaking force of ~0.7 N large changes in sensory-perceived firmness are related with relatively small changes in the force required to break the tissue. Above this value of ~0.7 N, large changes in breaking force are related to relatively small changes in perceived firmness. Obviously, within the experimental design used here, below a breaking force of ~0.7 N sensory firmness measurements are more sensitive than fracture measurements. Above 0.7 N the situation becomes reversed and the mechanical measurement used is more sensitive than the sensory-perceived measurement. The same biphasic behavior can be observed when the breaking force is plotted against the other mouthfeel descriptors used in this study (data not shown). For the potato samples studied, the fracture force required to break the potato tissue of the cooked potatoes, without any preceding heating process, ranged from 0.14 to 0.60 N. In other words, in the range were large sensory changes are observed, the wedge measurement is relatively insensitive. This suggests that the wedge fracture method is not suitable to be related with the sensory-perceived texture attributes.

Preheating and Pectin Methylesterase Activity. PME is an enzyme assumed to exhibit a “firming” effect on the texture of potatoes as a consequence of preheating (*18*). An extensive discussion about this issue has recently been published (*6*). To obtain information about the effects of both storage and preheating on the PME activity, this activity was analyzed for both the field-run and stored potatoes during preheating either for 0−60 min at 60 °C (see **Figure 3**) or for 10 min at 78 °C. For the field-run and stored potatoes, the range in PME activity is almost one decade. During the entire preheating period, up to 1 h at 60 °C, the PME activity seems to be rather constant for the potato samples studied. Preheating at 78 °C for 10 min almost completely abolishes the enzyme activity (data not shown). No obvious relationship can be discerned in the PME activity concerning cultivar, size, DM content, or storage. For both cultivars the potato samples of the small potatoes with a low DM content exhibited the highest PME activity.

Effect of Preheating and Cooking on the Yield of the Cell Wall Material and the Sequentially Extracted Pectin Fractions. The relationship between cultivar, size, DM content, and storage on the chemical composition of the pectin moiety of the cell walls of raw potatoes was researched previously (*12*). In the current study the effects of preheating and preheating followed by steam-cooking on the changes in the yield and chemical composition of the pectin moiety of the cell walls were analyzed. For small potatoes of cv. Irene with a high DM content the observed sensory textural changes upon preheating were the most pronounced (see **Figure 1B**,**D**). For this reason potatoes from this sample were selected to study the effect of preheating alone and preheating followed by steam-cooking on the yield and chemical composition of the pectin moiety of the cell walls. In **Table 2** the yield of CWM at different processing stages and conditions is presented. The CWM was fractionated by a stepwise increase in the harshness of the extraction medium (*12*, *19*). The yields of these sequentially extracted pectic fractions and residue are also presented in **Table 2**. The yield of the pectic fractions plus residue is 90 ± 11% ($n = 12$) of the yield of the CWM, emphasizing the gravimetrical correctness of the method applied (*12*). From this table it is obvious that the yield of the CWM and of the sequentially extracted pectic fractions of the samples preheated at 60 °C is substantially higher than that of the samples either pretreated at 78 °C or not preheated at all. To a great extent this is caused by the contribution of glucose. This sugar probably originates from the enzymatic degradation of starch at this temperature. Analysis of the sugar composition of the CWM showed that the percentage contributions (w/w) of glucose were 4% for the raw potatoes and 71 and 3% for the potatoes preheated at 60 and 78 °C, respectively. After cooking, these percentages were, respectively, 9, 49, and 15%. Given the high contribution of glucose, especially for the potatoes preheated at 60 °C, glucose was excluded from the information presented below.

The focus of the fractionation is on the pectin moiety of the cell wall. In **Figure 4** the yield of the sequentially extracted pectic fractions, corrected for the presence of glucose, is shown for the raw material and cooked potatoes preceded by different preheating treatments. These changes clearly show the consequences of the several preheating conditions on the yield of the sequentially extracted pectic fractions. For each fraction,

Table 2. Yield and Compositional Information of Cell Wall Material and of Sequentially Extracted Pectic Fractions of Fresh, Preheated, and Cooked Potatoes

yield and composition		sample					
		raw	60 °C for 30 min	78 °C for 10 min	raw + cooking	60 °C + cooking	78 °C + cooking
yield of							
cell wall material							
CWM	mg/g of DM	5.2×10^1	1.2×10^2	3.5×10^1	1.0×10^1	8.0×10^1	2.7×10^1
pectic fractions							
CDTA	mg/g of DM	9.7	2.3×10^1	7.7	4.4	1.0×10^1	5.2
carb 4 °C	mg/g of DM	8.7	9.5	7.5	3.5	1.4×10^1	5.6
carb 20 °C	mg/g of DM	5.3	4.4×10^1	3.4	7.2×10^{-1}	6.2	2.1
KOH	mg/g of DM	4.8	2.1×10^1	3.2	8.1×10^{-1}	1.3×10^1	3.2
residue							
residue	mg/g of DM	1.5×10^1	1.2×10^1	1.1×10^1	1.1	1.4×10^1	7.8
% yield		83	96	94	105	73	88
composition of							
cell wall material							
CWM	UA/Rha	1.2×10^1	1.2×10^1	1.5×10^1	9.7	1.3×10^1	1.2×10^1
	UA/NS	4.9×10^{-1}	5.2×10^{-1}	5.2×10^{-1}	3.5×10^{-1}	5.2×10^{-1}	4.5×10^{-1}
pectic fractions							
CDTA	UA/Rha	2.4×10^1	2.9×10^1	1.3×10^1	1.2×10^1	1.8×10^1	9.5
CDTA	UA/NS	1.1	1.3	5.9	4.8	7.3	3.7
carb 4 °C	UA/Rha	9.7	1.1×10^1	1.0×10^1	5.7	8.2	6.5
carb 4 °C	UA/NS	5.2×10^{-1}	5.8×10^{-1}	4.8×10^{-1}	2.5×10^{-1}	3.5×10^{-1}	2.7×10^{-1}
carb 20 °C	UA/Rha	7.2	$1.2\ 10^1$	6.7	6.5	9.0	6.4
carb 20 °C	UA/NS	2.7×10^{-1}	4.3×10^{-1}	2.3×10^{-1}	2.1×10^{-1}	2.7×10^{-1}	2.1×10^{-1}
KOH	UA/Rha	5.2	nd	5.7	4.0	$1.9\ 10^1$	6.1
KOH	UA/NS	1.6×10^{-1}	5.5×10^{-1}	1.5×10^{-1}	1.1×10^{-1}	1.8×10^{-1}	1.4×10^{-1}
residue							
residue	UA/Rha	nd	nd	nd	nd	nd	nd
residue	UA/NS	3.7	3.6	3.2	2.8	3.6	3.0

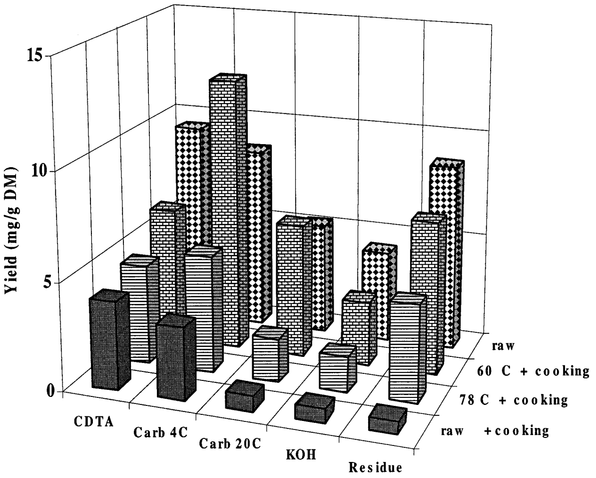


Figure 4. Yield, corrected for the amount of glucose, of sequentially extracted pectin fractions of raw potatoes and preheated, cooked potatoes.

the yield increases in the following range: no preheating, 10 min of preheating at 78 °C, and 30 min of preheating at 60 °C.

Effect of Preheating and Cooking on the Chemical Composition of the Cell Wall Material and of the Sequentially Extracted Pectic Fractions. The consequences of preheating and cooking on the compositional information of the sequentially extracted pectic fractions are presented in **Table 2**. Measures for the composition of pectin are its linearity and side-chain extent (*12*, *20*). The main chain of pectin consists of a linear polygalacturonic chain interspersed with (1→2)-linked α-L-rhamnopyranosyl residues, causing kinks in the chain (*21*, *22*). A decrease in the ratio of the molar amount of galacturonic acid over the molar amount of rhamnose (UA/Rha) goes at the expense of the linearity of the main chain. The pectin polymer also contains side chains. These side chains are covalently bound to the rhamnopyranosyl residues and mainly contain neutral oligo- and polysaccharides (*21*, *22*). The ratio of the amount of galacturonic acid over the sum of the main neutral pectic sugars Ara, Rha, and Gal (neutral pectic sugars; NS = Ara + Rha + Gal) represents a measure for the side-chain extent (*12*, *20*). These values for the linearity and side-chain extent are important characteristics to describe pectin and are presented in **Table 2**. No specific trend can be observed concerning the values for the linearity and side-chain extent of the pectic fractions isolated in relation to the applied processing conditions. A PCA (data not shown) shows clustering of the raw potatoes, the potatoes preheated at 60 °C, and the potatoes preheated at 60 °C followed by cooking.

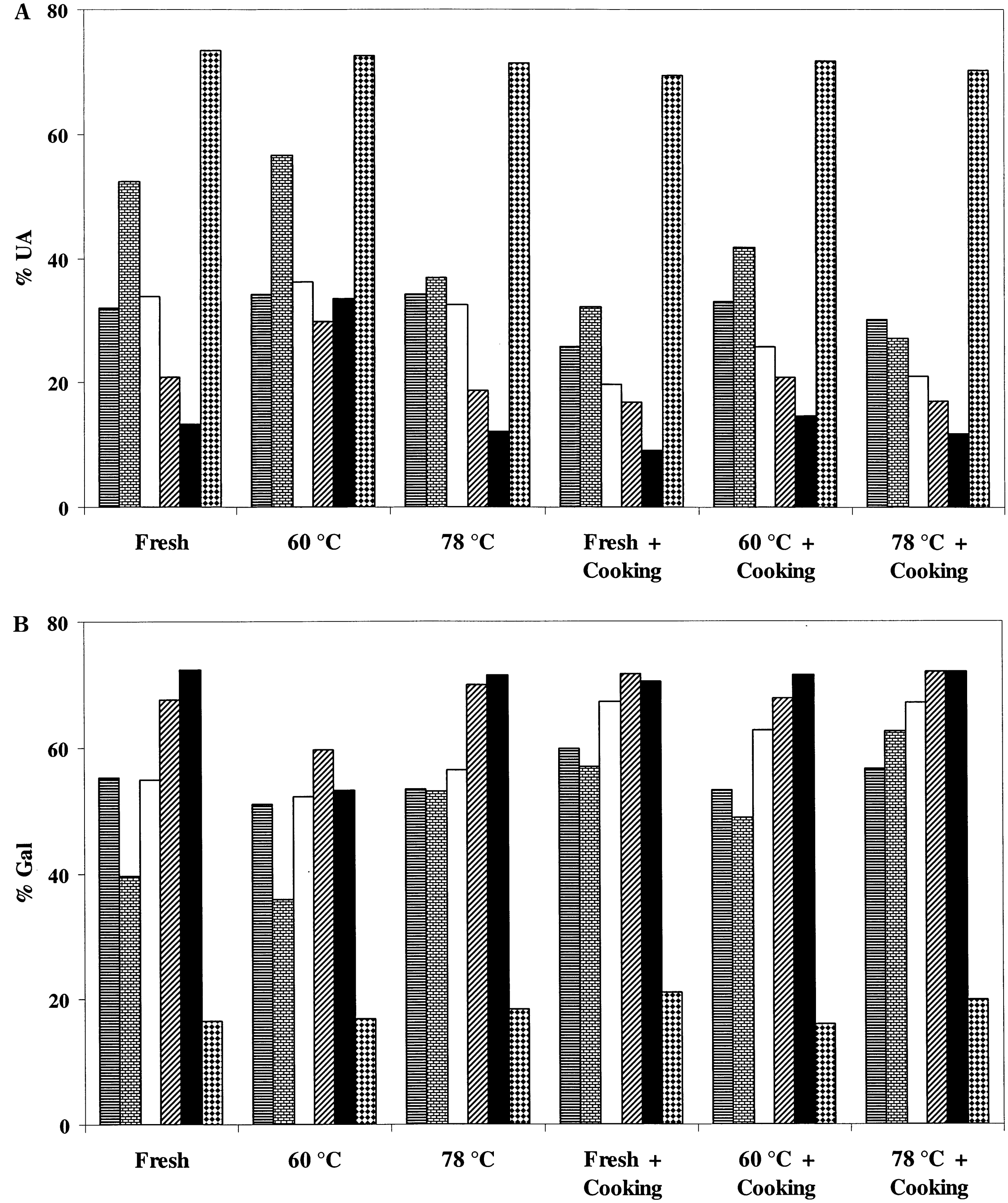
In **Figure 5** the pectic sugar composition, expressed in mole percent, corrected for glucose, of major, individual pectic sugars present in the fractions obtained during the pectin fractionation procedure, is given.

The average percentage coefficients of variation [12 for all measurements ($n = 36$)] were for Rha, Ara, Gal, UA, and Glu 2.4, 2.2, 2.1, 0.7, and 3.4%, respectively. No large effects can be observed for preheating or preheating followed by cooking on the percentage contribution of the individual sugars in CWM, the sequentially extracted pectin fractions, and the residue. Noticeable is the virtual absence of Rha and the relatively large amount of UA in the residue.

DISCUSSION

The potatoes used in this study were from a different season than the potatoes studied previously (*3*). Predictions of the DM_{UWW} and the starch content could be performed on basis of the statistical models developed for potatoes from a previous harvesting period (*3*). It has to be realized that model development and model validation were performed on a limited set of potato cultivars, suitable for human consumption, representing two extremes in texture.

The combined instrumental and sensory analysis showed that, despite the low number of trained assessors used in this study,



the consequences of preheating on the texture development of potatoes are obvious (see **Figure 1**). The general tendency is that an increase in preheating time at 60 °C results in a product which requires a greater force to break the tissue. With respect to the sensory-perceived changes, a more firm-M and a less mashable-M product is obtained. The magnitude of the effect of preheating on the changes in the instrumental and sensory-perceived texture seems to be strongly related to the DM content. It was observed that the higher the DM content, the more pronounced the effect (see **Figure 1B**,**D**).

When instrumental firmness measurements, with emphasis on the wedge fracture test (*9*), are related with the sensory-perceived firmness descriptor, firm-M, two regions can be distinguished. One region is characterized by the larger sensitivity of the sensory over the instrumental measurements. The other region is characterized by the larger sensitivity of the instrumental over the sensory measurements. The texture of potatoes cooked without preheating is located in the region characterized by the larger sensitivity of the sensory over wedge fracture test. Previously, it was shown that, using compression measurements, the rates of tissue softening during cooking are different for cv. Irene and Nicola (*17*). However, compression measurements were not capable of distinguishing between the firmness of the cooked potatoes from these two cultivars representing extremes

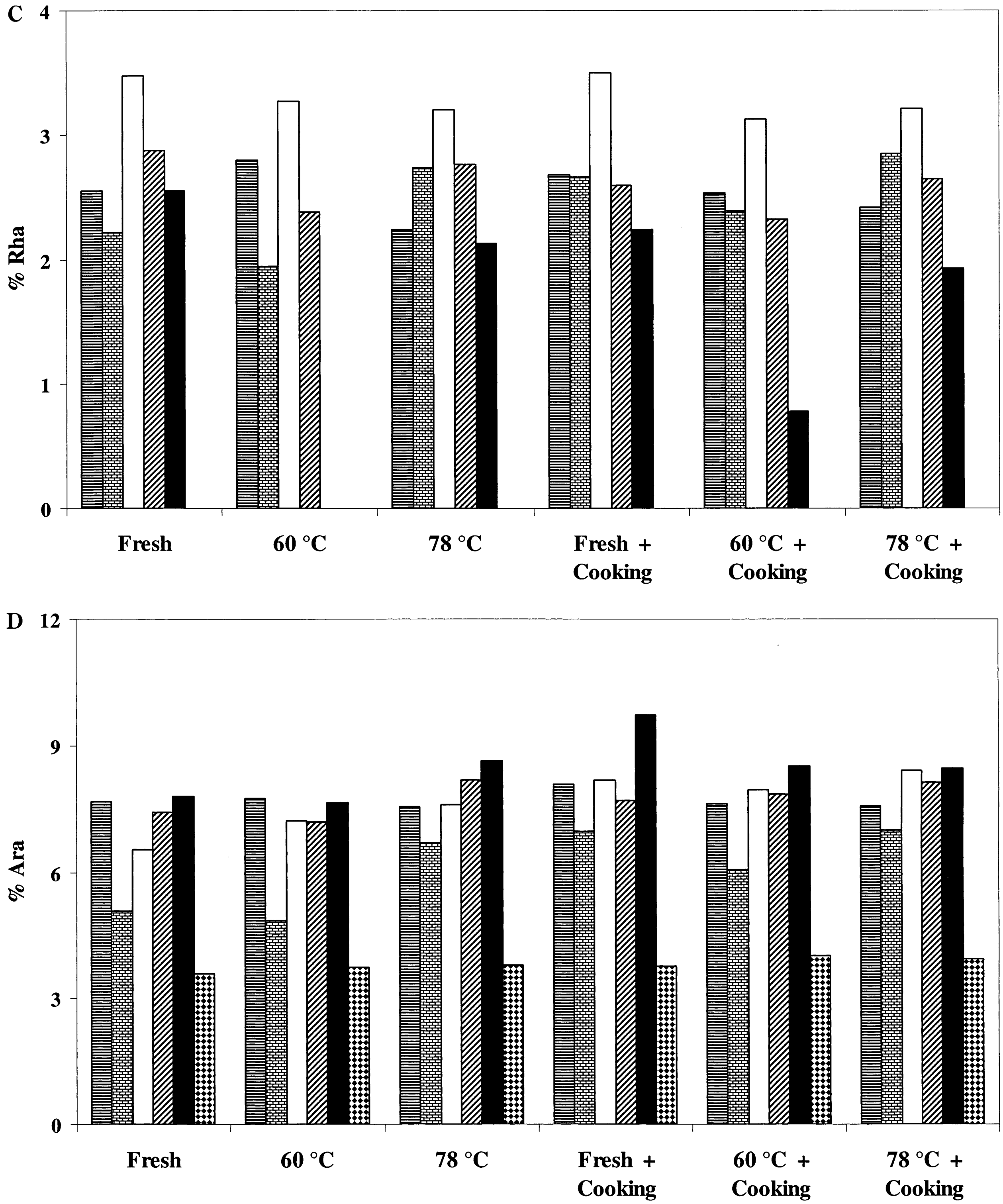


Figure 5. Chemical composition, expressed as mole percentage amount of main pectic sugars, of the cell wall material and sequentially extracted pectic fractions of fresh, preheated, and preheated + cooked potatoes: (A) uronic acid; (B) galactose; (C) rhamnose; (D) arabinose; (horizontally striped bars) cell wall material; (brick-patterned bars) CDTA extract; (open bars) Na_2CO_3 extract at 4 °C; (slashed bars) Na_2CO_3 extract at 20 °C; (black bars) KOH extract; (diamond-patterned bars) residue.

with regard to texture. Thybo and Martens (*10*) also concluded that texture profile analysis data were not relevant substitutions for sensory attributes. Recently, Ng and Waldron (*23*) reported that prolonged preheating did not affect the instrumentally measured firmness of cooked potatoes of cv. Bintje. This, however, might be explained by the relative insensitivity of instrumentally performed firmness measurements. At this moment it seems therefore reasonable to conclude that, in contrast to, for example, green beans (*24*), the sensory-perceived texture of potatoes cannot be linearly related with rheological measurements.

PME is the enzyme assumed to be responsible for the firming effect caused by preheating (*5*, *18*). Recently the kinetics of the PME activity in potatoes, cv. Bintje, has been described (*25*). As can be concluded from this information, the PME activity of potatoes of cv. Bintje should be virtually abolished after preheating at 60 °C for 1 h. However, in the current study almost no change in PME activity was observed for cv. Nicola and Irene at this preheating temperature. This could be caused by a balance between heat-induced PME denaturation and heat-induced transformation of PME from a catalytically inactive into an active form (*25*). Other options are that cv. Nicola and Irene contain a different, more heat stable PME isoenzyme from cv. Bintje or that the total amount of enzyme in Bintje is too low to have consequences regarding firmness changes in relation to preheating (*23*). Anyway, preheating at 60 °C causes potatoes to become firmer (**Figure 1B**,**D**). Furthermore, preheating at this temperature resulted in a higher yield of pectin in the CWM as well as the sequentially extracted fractions (see **Figure 4**). This increase in yield, as a consequence of preheating, is in agreement with the assumed effect of PME activity leading to a decrease in β-degradation of pectin during cooking. Both observations confirm, although in an indirect way, the firming effect of PME.

With regard to the chemical composition of the sequentially extracted fractions, no substantial differences can be observed (see **Table 2**).

Previously it was concluded that the texture of directly cooked potatoes is mainly determined by starch. The contribution of the cell wall polymers to the texture was predominated by the contribution of starch (*3*, *12*). Prolonged preheating at 60 °C causes the pectin to become substantially less vulnerable for β-degradation during cooking. The consequences of this decrease in pectin degradation are a higher yield in pectic CWM and a firmer product.

Recently Binner et al. (*8*) suggested that the firming effect is not caused by PME activity but by the breakdown of starch oligomers that can escape from the cell. They also concluded that PME was still active at 100 °C. On the basis of the results presented in this study and previous results (*25*), it seems very unlikely that potato PME is still active at 100 °C. We also observed substantial amounts of glucose in the CWM of potatoes pretreated at 60 °C, but not at 78 °C. At this moment it can therefore not be excluded that the starch breakdown products might contribute to the texture of cooked potatoes preheated at 60 °C.

ABBREVIATIONS USED

Ara, arabinose; carb, carbonate; CDTA, cyclohexane-*trans*-1, 2-diaminetetraacetate; CWM, cell wall material; DMSO, dimethyl sulfoxide; DM, dry matter; Gal, galactose; Glc, glucose; Man, mannose; Rha, rhamnose; RMSEP, root-mean-squares error of prediction; TFA, trifluoroacetic acid; Xyl, xylose; UA, uronic acid; WIR, water-insoluble residue; WSP, water-soluble polymers.

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